NATIONAL RADIO INSTITUTE

Certified Radio-Trician's Course
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NRI

FUNDAMENTAL PRINCIPLES OF RADIO

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Originators of Home Study Radio Courses
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FOREWORD

Because Radio is the result of the development of the science of electricity, the fundamental principles that underlie both are identical. The invention of the vacuum tube can be said to mark the birth of Radio as it is known today, and since then Radio has developed as a separate science.

However, we can't start our study of Radio with the vacuum tube—it is first necessary to get a thorough knowledge of the principles of electricity so that when we study the vacuum tube we shall be able to understand both the "how" and the "why" of its construction and operation. It is necessary to know something about electricity, how it works, the different kinds of electricity there are (every kind used in or has some connection with Radio).

You can be sure that you will not be expected to learn anything that is not absolutely necessary for a complete understanding of Radio, so give these first lessons as much care and attention as you will give the later lessons dealing with Radio apparatus and its operation. You will be learning Radio all the time, and you will be learning it right—first getting a firm foundation on which to build. A man would be foolish to attempt to build a beautiful home on a weak foundation—we are not going to make that mistake.

Just a word of warning. You may be tempted to "skip" here and there throughout these first lessons. Don't do it. You may miss something that is absolutely essential. Even though you may have some knowledge of electricity, a thorough study of these lessons dealing with fundamental principles will fill in the gaps and loopholes of your present knowledge. Only by reviewing these fundamentals in the light of recent developments will you get the background needed for a complete understanding of later lessons.

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Fundamental Principles of Radio

WHAT IS ELECTRICITY?

In our study of Radio, we will be dealing with electricity a large part of the time. Naturally we will have to know something about electricity even before we begin to talk about Radio.

You are most likely very familiar with the use of electricity. You know it will light a room or run a trolley car, but do you know anything else about it? You have never *seen* an electric current—you know it travels through wires, you know that in Radio not even connecting wires are necessary between receiver and broadcaster, but just what is this "current" which is so powerful that it is doing a large part of the world's work?

Now we are going right to the bottom of the matter and in this very chapter you will get a clearer insight into the nature of electricity than many electricians have. In fact, as a trained Radio Expert you will know considerable about electricity—while the electrician is not so fortunate. His training and experience have not taught him very much about Radio.

For many years, even long after electricity was harnessed and made to run motors, scientists were unable to decide just what electricity really was. Even today there are some points in connection with it that are not entirely clear, but enough has been learned about it to give us a fairly clear idea of what goes on in an electric circuit, and how it is that a voice can be carried from one end of the country to the other in much less than a second of time, with and even without the use of connecting wires.

Years ago it was discovered that everything in nature was made up of "atoms"—the earth, the food you eat, the water you drink, the air you breathe. Now you will want to know what we mean by an atom. Let's take something very small and try to find out what it's made of.

Suppose we take a grain of salt—we could use a grain of sand, or anything else—and break it up. You can easily imagine a grain of salt ground up into a fine powder. Now we separate

a tiny particle of this powder and crush it. Again we would have still smaller particles, but they would still be salt. However, by continuing the breaking up of salt particles we come to a point where something very peculiar happens. At a certain stage of this breaking up process *we do not have salt any more.* Our tiny particle of salt has been divided into two different substances and these are "atoms." In the case of salt, the "atoms" or "atomic substances" are chlorine and sodium.

There is a name given to the smallest particle in which the atoms are still combined—the "molecule"—which is in other words, the smallest particle that is still salt. Remember, this is true not only of salt but of everything else in creation—everything can be broken up into molecules, and molecules are nothing but combinations of atoms.

When the atom was first discovered it was believed that it could not be divided. In fact, the word atom means "cannot be cut." So atomic substances were thought of as being elements. There were about ninety-six of these including carbon, copper, oxygen, hydrogen, etc. And so it was proved that the only difference, between the water in a glass, for instance, and the glass itself, was that they were composed of different combinations of atoms or atomic substances.

But modern scientists have gone beyond the atom. By discovering a means of "cutting" the atom, they have discovered the "electron." They have found that the atom consists of a "nucleus" or center, surrounded by one or more *moving* electrons, and that the atoms differ from each other only in the number of electrons each contains. Fig. 1 shows the difference between an atom of hydrogen and another slightly more complex atom, as they are generally imagined to be. Concerning the nucleus, much remains to be learned, but for our purposes, we have gone far enough in science when we have reached the electron and learned something about it.

If it were possible to enlarge the atom so that we could see it with the naked eye, we would observe some peculiar things about electrons. We would notice, for instance, that they do not touch each other, that they seem to be moving in space about the nucleus. This space is called "ether" by scientists and must not be confused with "air" as we know it, which is full of various gases and so is itself composed of atoms having electrons. This ether has no connection with the medicinal ether which doctors use. When we use the word "ether" we mean "nothingness"—if

you can imagine that—but for our purposes we use the word "ether" to mean "something" which will exist after all atoms have been removed from a position which the atoms occupied. There is no known method for removing the "ether" itself. Therefore, the existence of a *material* ether is a convenience adopted by many scientists to help imagine a medium in which these infinitely small particles exist. It is what is left in a light bulb after the air (molecules) has been pumped out.

Then we would notice something else. No matter how many electrons there were in the atom each would be at a definite distance from each other. If one were to be jarred ever so slightly, immediately many of the others would shift so that the original position would be maintained. Some of these electrons, however, remain close to the nucleus and cannot be removed by any known electrical or chemical means. There are always

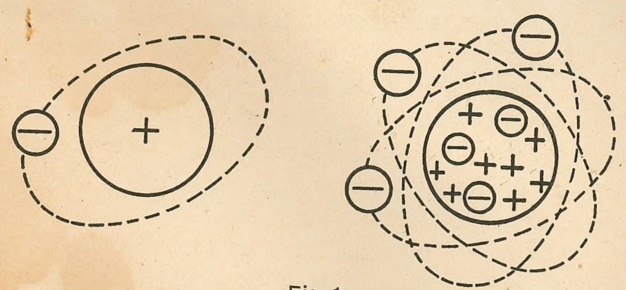


Fig. 1

many more electrons which hold their positions close to the nucleus than those which move when they are forced to do so by electrical means. The electrons which can move away from the nucleus are called "free electrons" and are exactly like the "fixed" ones in every other respect.

What will this mean to us? It will mean that the electron is "alive," that is, it has a certain energy or force in it which affects other electrons.

You are no doubt familiar with the common horseshoe magnet as shown in Fig. 2. You have often seen a nail or a small piece of iron drawn to the open end of a magnet. What is there about a magnet which causes a piece of iron to move toward it? We say it has an attracting force of energy. Exactly what this is in the case of the magnet we will take up in a later lesson. It is enough now to understand what we mean by the word "force."

The electron exerts a "push" to all of its neighbors. It forces itself away from them instead of drawing or attracting other electrons to itself. Imagine three electrons in a line 1 2 3. The second will be exactly half way between one and three. Now suppose number one is moved forward a quarter of an inch. Immediately two and three will be pushed forward exactly the same distance.

This is, of course, all in our imagination. The electron is so small that we can't actually look at it or handle it. To give you an idea of its size—the tip of a needle is about the smallest thing I can think of in ordinary life—and it takes billions and billions of electrons to make the atoms, that make the molecules, that make the tip of a needle.

By this time you will have guessed that the electron has a good bit to do with electricity, and you are right!

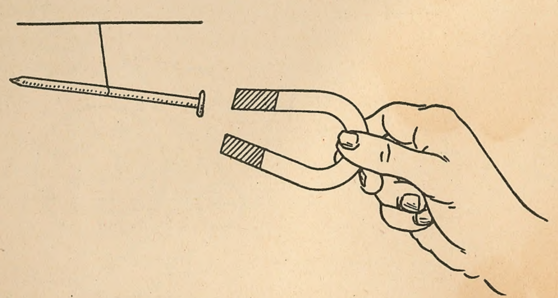


Fig. 2—Horseshoe magnet attracting a suspended nail.

Now what do you know about a length of copper wire? From what you have already learned in this chapter, you know that it is made up of copper molecules. These molecules are combinations of various atoms. And the atoms are composed of electrons and "nuclei."

The electrons composing the wire are grouped about the nuclei and are always ready to put up a fight to keep their places. It takes energy to move them out of their position. They are continually revolving around the nuclei at great speeds but until forced to do so they do not leave their respective path. Suppose something happens to move the electrons at one end of the wire forward. Immediately there is a shift. Many of the electrons must move forward to new positions and these are the free electrons. This movement of electrons is a flow of *electric current.* (See Fig. 3.) Here, at last, we have what we started out to get. From a grain of salt we have worked around

to the flow of electric current and so have learned considerable about the theory of electricity.

We have said that it is the movement of electrons in an electrical circuit that is a flow of electric current.

Right here we want to impress on your mind the terrific speed at which electrons react on each other. If we had a wire stretched from New York to San Francisco, and there was a disturbance of electrons at one end, the electrons at the other end would feel the effect of this disturbance in 1/60th of a second, for electrical disturbances travel at the rate of approximately 186,000 miles per second.

Now we have talked about disturbing the electron and you have naturally wondered just how electrons are put into motion.

You are familiar with the ordinary electric battery, the kind that supplies the power for some radio receiving sets, door bells, etc. In the battery are various chemicals—we'll learn just what they are later—which are capable of acting on

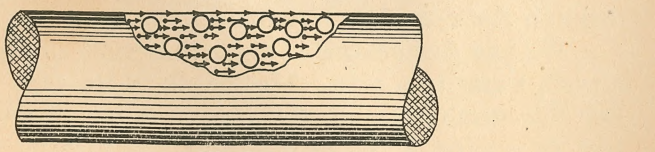


Fig. 3

each other in such a way that some electrons of which they are formed, become separated from their atoms and gather on one of the battery terminals.

One terminal of a cell or battery is called *positive.* The other terminal is called *negative.* These terminals were so called *just to give the terminals a name.* You will therefore understand that the words "positive" and "negative" are only "names" which will identify a certain "end," "terminal," "place," or in fact "anything." If the ends of a copper rod are connected by a wire to the two terminals of an electric battery to form a complete circuit as illustrated in Fig. 4 the free electrons will move slowly from the negative terminal of the battery along the wire towards the copper rod. They leave the copper rod at the end marked + and travel down the wire to the positive terminal of the battery. In other words, as fast as the electrons leave the + end of the copper rod, they are supplied at the — end.

This is strictly true, however, before the discoveries were made that led to the electron theory, physicists believed that

the current flowed from the positive terminal of a circuit, back to the negative terminal. These two theories are, therefore, in contradiction to one another, but due to the fact that the whole foundation and operating principles in the development of electrical engineering were founded on the old theory, this custom cannot well be changed in all cases, so we must still speak of the current as flowing from the positive terminal to the negative in some cases, covering the action of motors, generators, transformers, batteries, etc., but it is well to bear in mind that the thing that really flows in the wire or circuit as we know it today is a stream of electrons from the negative to the positive terminal.

The cause of this flow or movement of electrons is the chemical action within the battery which maintains a push or constant pressure (voltage) at the ends of the copper rod. This action would be the same if the pressure was provided by other means such as a generator because the battery or generator is acting as we might say like a pump for pumping electrons through the complete circuit.

We can demonstrate this action very nicely by comparing it with water in a pipe. The length of the pipe will not matter. For our demonstration the pipe will have to be full of water just as a wire is full of electrons. Returning to our pipe full of water—we force a quart of water into one end by the pump. What happens at the other end? Naturally a quart of water will be forced out. But the water forced out is by no means the *same* water that we put in. This is, of course, a very crude illustration, but we want to get very clearly in your mind that electrons from a battery do not travel very rapidly and yet the effect is almost instantaneous throughout the circuit. The electron itself does not go through 186,000 miles of wire in a second. But it causes a disturbance of the electrons and the disturbance is felt instantaneously throughout the entire circuit.

For instance, when you push an electric light button, an electric circuit is closed and a current starts to flow through the circuit immediately. Remember that this flow of electricity is nothing but a continued disturbance and movement of the electrons in the circuit.

Now we are going to leave the electron and our study of the nature of electricity for a while in order to take up in this first lesson other fundamental principles of Radio. Our purpose is

to get a bird's-eye view of the natural laws which make Radio possible. So far you have obtained considerable knowledge of electricity. In fact, right now you know more about the nature of electricity than the greatest scientists did until a few years ago.

MAGNETS AND MAGNETISM

Natural magnets found in various parts of the world, composed of an "oxide of iron," called *magnetite*, have the peculiar property of attracting pieces of iron or steel when placed near to them. These natural magnets also have the property of pointing nearly due North and South when suspended or pivoted. These natural magnets received from the early mariners the name Leiderstan (i. e., leading stone). The name was subsequently changed to the English word Lodestone. When a bar of

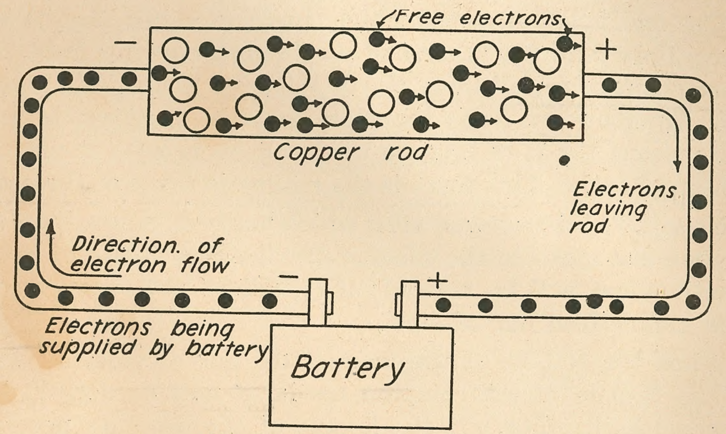


Fig. 4

steel is rubbed with a piece of lodestone the steel becomes magnetized and is known as an *artificial magnet.* If this steel bar is dipped into a pile of iron filings some filings will be attracted to the tips of the bar. Magnets are divided into two classes, *Permanent* and *Temporary.* Permanent magnets are those which retain their magnetic effect for a long period of time. These magnets are made of very hard steel. Temporary magnets are those that retain their magnetism only during the time which they are in contact or under the influence of another magnet or are being energized by an electric current. These magnets are made of soft iron or a real soft grade of steel. A coil of wire wound around a bar of iron or steel will have magnetic properties when a current is passed through the wire.

An iron core, surrounded by a coil of wire is called an *electromagnet*. Such a magnet is a magnet only when current flows through the coil. When the current is stopped, the iron core returns almost to its natural state. Electromagnets are used for a variety of purposes in radio, such as for testing buzzers, headphones, generators, motors, relays, etc.

A compass consists of a small magnetized piece of steel (the magnet needle) mounted on a vertical pivot which is enclosed in a brass box with a glass top so as to prevent air currents from interfering with the position taken by the needle.

If the compass needle is allowed to move freely, one end of the needle will point toward the *North* of the earth, with the axis of the needle in a *North* and *South* line. Any magnet which is free to move will do the same thing.

The end pointing toward the North is called the "North Seeking Pole" and the other end the "South Seeking Pole." It is more common to call them North Pole and South Pole respectively. Some unseen force, therefore, must be drawing the poles of the magnet for it to turn on the pivot or to keep it pointing North and South. This force is the magnetic force of the earth.

Now if we take a bar of steel which has been magnetized and place one end close to the magnet needle, the effects of a new magnetic force will be noticed; that will be the force exerted by the magnetized bar of steel.

When the N pole of the magnetized bar of steel is placed near the N pole of the compass needle it will be noticed that they repel each other. If the S pole of the compass needle is approached with the S pole of the magnetized bar, again the needle will be repelled. These are like poles (similar). If unlike poles are approached they attract. (See Fig. 5.) It is important to realize that the "magnetic force" is always associated with a magnet, whether the magnet is acting on a compass, piece of steel, iron or not—or put it this way—whether the magnet is working or not. The space over which this magnetic force extends is called the magnetic field. And now we want to show that it is easy to imagine the force in the field as extending from the magnet in lines, called "lines of force."

If a small compass needle is placed anywhere near a bar magnet, the needle takes a definite position.

If a bar magnet is placed under a sheet of paper and then the compass needle is put down at a number of positions and

the direction that the "North Pole" points marked down on the paper, we will find a picture of the field of force something like that shown in Fig. 6. This figure shows that the magnetic force of the field acts along lines and that the field has definite direction at every point.

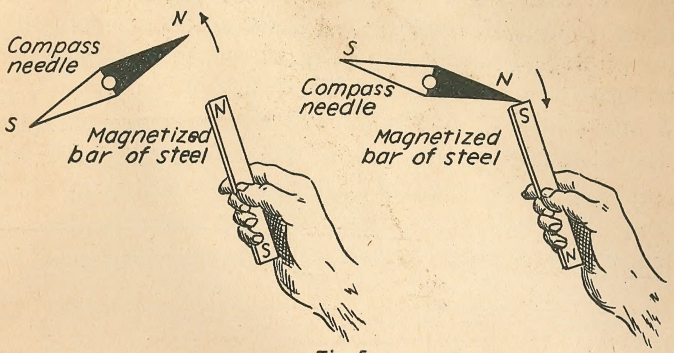


Fig. 5

The field of force around a bar magnet can be seen more clearly by placing a sheet of paper over the bar, dusting fine iron filings on the paper, then by tapping the paper gently. The result of this process will be to secure a formation of the little lengths of iron like that shown in Fig. 7. The iron filings have become innumerable little compasses.

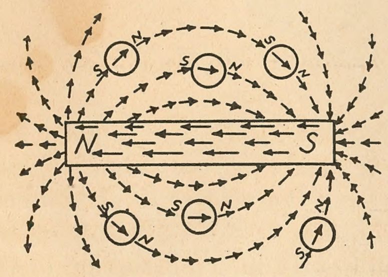


Fig. 6—Magnetic lines around a bar magnet.

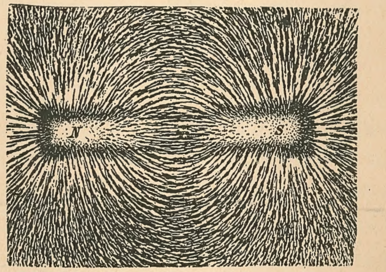


Fig. 7—Formation of iron filings around a bar magnet.

If a small compass is brought near a wire carrying a current a decided force is also exerted in the direction in which the needle points. Thus, suppose a wire, carrying a current, is coming directly up out of the paper as shown in Fig. 8(a), the compass needle would show the direction of the force around the wire. What do you think is the cause of this strange action of the compass needle? Well, you know that it is magnetism that

causes the needle to point North ordinarily, so there must also be magnetism around the wire when it is carrying a current. From this we can conclude that any wire, carrying a current, has magnetic properties and that around a live wire there is a magnetic field consisting of lines of force.

Further experimenting would show that the magnetic field, consisting of lines of force, gets bigger as the current increases, disappears or collapses when current stops, and reverses if the current is reversed. (See Fig. 8 (b).)

In our study of Radio, it will be necessary sometimes to know the direction of the lines of force in a magnetic field of a wire carrying current, without having a compass to show their direction. This will not be difficult if you learn the lines of force around a wire carrying current are always clockwise if you con-

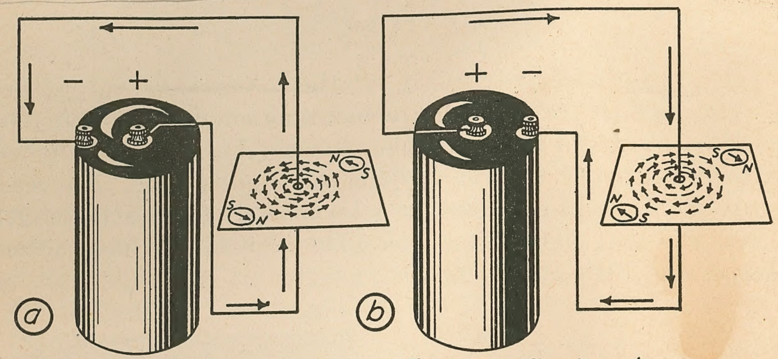


Fig. 8

sider the current flowing away from you. Here is a good way to get a clear idea of this and fix it firmly in your mind. Clinch your right-hand, then bend back your thumb as far as you can. Consider that your thumb is pointing in the direction of the current flow, then your fingers will point in the direction of the lines of force. (See Fig. 9.)

If a wire is made up into a coil, and a current sent through it, there will be produced a concentrated magnetic field such as shown in Fig. 10 (a). This is because each turn of wire has its own lines of force which combine with the lines of force of other turns of wire in the coil.

All together these lines of force form a single magnetic field for the entire coil. The field thus produced is exactly similar to that produced by a magnet, for it has polarity; (N and S poles).

(See Fig. 10 (b).) If the coil with current in it were suspended and allowed freedom of movement, it would turn and stand with its axes in an N and S line as a magnet needle would do; if we explore the lines of force with a magnet needle, we find they run through the coil S to N as well as outside N to S.

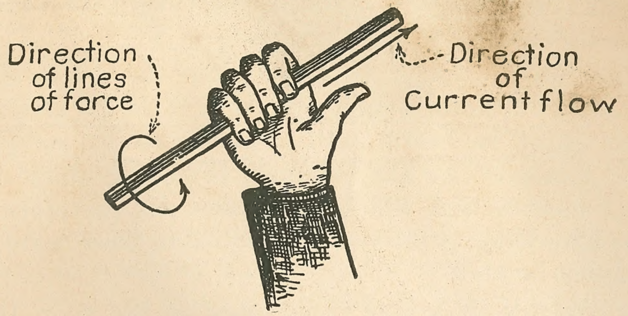
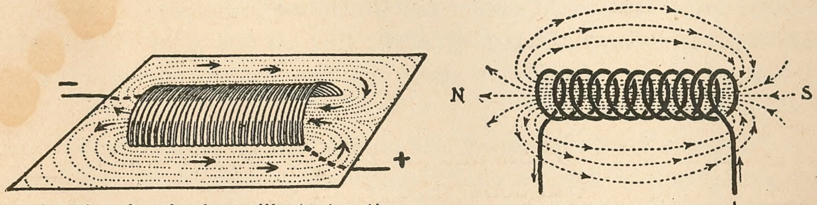


Fig. 9—Right hand rule for direction of current flow.

If a rod of steel is inserted into the coil and current is passed through it, the steel will become a permanent magnet. If instead of the steel we insert a rod of iron into the coil it also becomes a magnet, but it is only magnetic so long as the current lasts. This is called an electromagnet.

A knowledge of magnets and magnetism is of the utmost importance in getting a thorough understanding of Radio. In



(a)—The sketch above illustrates the magnetic field surrounding a coil of wire carrying current.

(b)—Lines of force about a coil of wire carrying current.

Fig. 10

our study of Radio we shall often study the effects of lines of force of various magnetic fields, we shall see later how lines of force cutting a wire can produce a voltage in another wire and how energy can be transferred from one part of a radio receiver to another, by these magnetic lines of force, even though there is not actual contact between the parts. Then we shall see also how the same principle is applied so that energy is transferred between a transmitting and receiving aerial.

RADIO WAVES

To understand how Radio signals can be sent and reproduced from a receiving set, a study of wave motion and its characteristics is essential. In transmitting voice or music by Radio, *sound waves* are converted into electrical vibrations, which are then again converted into *Radio waves* (magnetic waves), and finally change back into *sound waves*.

Sound waves cannot be seen. Likewise, electromagnetic waves used for Radio communications cannot be seen; neither can their effect be heard until transformed by receiving apparatus. However, we are fortunate in having many other examples of wave motion, which can be seen and therefore studied. Then the knowledge gained can be applied to those wave motions which cannot be seen.

For example, if a long rope, lying on the floor, is shaken sideways briskly, by moving it to the left and then to the original position, a single wave-like motion is given to it, which will travel down its length as shown in Fig. 11(A). If the rope is shaken twice, two waves will be started which travel away to the other end, keeping always the same distance apart, this being shown in Fig. 11(D). If the shaking is repeated *harmoniously* (rhythmically), a continuous wave motion is started which transmits the energy imparted by the hand to the other end of the rope. Try this experiment yourself by taking a flexible rope or hose, twenty feet or more long, and shaking it sideways as it lays along a straight line on the floor. This will give you an opportunity to study the wave motions which now will be described.

In order to understand the properties of waves, and these properties apply also to electromagnetic waves, we must know something about the terms used to describe them. A clear understanding should be had of the terms; medium, velocity, amplitude, cycles, wavelength, period and frequency. All these are necessary to describe a wave motion. No doubt you have already used some of these words yourself, to describe other actions besides wave motion, so see how they fit in with your present knowledge of the terms.

All types of waves, including heat, light, water, sound, and Radio, are produced in mediums which are needed to allow vibration or oscillation to exist. That "something" through which a wave passes is called the *medium*. In Fig. 11, the *rope* is the

medium. *Air* is the *medium* for most sound waves which reach our ears. However, most physical substances, such as wood, steel and water are also mediums for sound waves. Thus sound waves may have several mediums. A *vacuum* is not a medium for sound, which can be proven, by ringing a bell in a closed jar from which the air can be pumped, and listening for sound waves. On the other hand, *Radio waves* will pass through all substances, including a vacuum, from which it is customary to say that *the ether* is *the medium* for *Radio waves;* and the *only* medium.

Let us now return to the "wave motion" of a rope and study the term "velocity" so that we can apply it to *sound waves* and *Radio waves.* It is best to study *single* waves first. This we can do very well by studying the waves produced in a rope because the motion can be confined within the medium in a *single* direction, while other mediums have the motions extending in more than one direction.

Have you ever fastened a long rope to the top of a post, then tried to wrap the rope around the post by sending "waves" along the rope as shown in Fig. 11? If you have, then no doubt you noticed that the shape of the wave could be controlled by the motion of the hand. Thus, a single wave could be sent along the rope which kept moving always as a "crest" or "hump" until it reached the post. Then, upon reaching the post the "wave" would reflect and come back on the under side of the rope as a "trough" or "hollow." Likewise, it is possible to control the motion of the hand so that the wave will start out on the under side of the rope as a "trough" and upon striking the post it will *reflect* as a "crest," traveling back to the hand if it has enough energy to travel that far. Similarly, a wave can be sent along the medium as a "crest and a trough combined," as shown in Fig. 11(C) by proper movement of the hand, which will return as a "trough and a crest" upon being reflected. (Sound waves and Radio waves also can be reflected.)

In each case the "wave" would travel a certain *distance* in the same amount of time. In other words a *wave motion* always has the same speed in the same medium. In your experiments with the rope on the floor, or tied to a post or wall, you will notice that the waves have a definite "speed" or "velocity." If you change the stiffness or thickness, even by pulling on the rope, you change its medium. When the *speed* is observed along a

definite direction, then "velocity" is the proper term to use. For practical purposes, *speed* and *velocity* mean the same thing.

Anything that travels must have "speed" or "velocity." When we say that a certain automobile is a speedy one, we are not satisfied. By adding that it will make 80 miles an hour, our curiosity is satisfied. One thing more; when we say that a non-stop aeroplane is flying with a "speed" of 200 miles per hour *from New York* to San Francisco, we have added direction. Then we say that the *"velocity* is 200 miles per hour" and we have completed our understanding of *velocity.*

Usually we like to express the *velocity* of any motion by numbers. How is this done? By observing the *distance* covered in a given time. Thus, the wave in the rope may travel 84 feet in 2 seconds. Then we would say that the *velocity* of the wave would be "84 feet *per* 2 seconds." However, we would simplify those numbers so that we would only speak of a *single* second instead of *two* or more seconds. Therefore the velocity of the wave in the rope would be also spoken of as "$\frac{84}{2}$ feet *per* second" or "42 feet *per* second." We readily realize that we *divide* the one number into the other number. That is, we divide the number of "distance units" (feet) by the number of "time units" (seconds) in order to get the "velocity units" (feet/sec.). In the above case the velocity units are called "feet *per* second." This unit is usually written $\frac{\text{feet}}{\text{sec.}}$ or feet/sec. From this we can see that the word *per* means *"divided by."* The "dividing line" in the unit means *per.* In a similar way we can now say that *"velocity"* is *"distance per time."* We can also let letters represent the three quantities of "velocity," "distance" and "time." Let V represent velocity, D the distance and T the time, then

$$V = \frac{D}{T}$$

The above equation is one which can be used to find the velocity of any motion.

You will quite often see the expression *per* used in other units, besides velocity units, so just keep its intention in mind as meaning "divided by."

The velocity of *sound waves* in air has been measured to be 1085 feet/sec. or nearly "1 mile per 5 seconds" (1/5 miles/sec.) or 331 meters/sec.

The velocity of sound waves in steel has been found to be 4726 feet/sec. or 1441 meters/sec.

Similarly, the velocity of Radio waves has been measured to be 186,000 miles/sec. or 300,000,000 meters/sec. *under all conditions.* Therefore, it must be evident that the medium does not change. The velocity of light waves has also been measured and found to have identically the same velocity as Radio waves. Likewise, an electric current has the same velocity as Radio waves.

The above figures show that the velocity of Radio waves, and

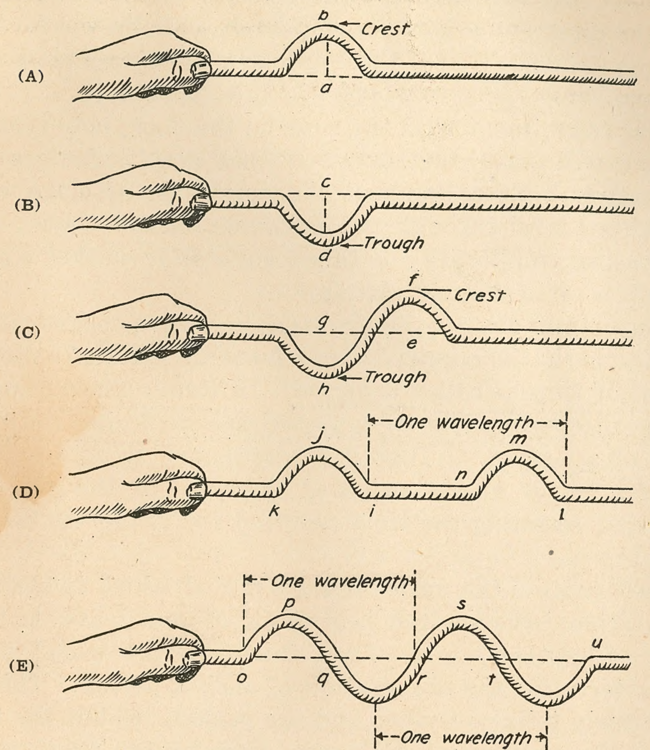


Fig. 11

the action of an electric current, is exceedingly great, having a velocity thousands of times greater than the velocity of sound waves.

Let us again return to the wave motion in the rope in Fig. 11(A). The wave will have a definite shape which can be controlled by the motion of the hand. Thus, it is possible to send out *three types* of "simple waves," as shown in Figs. 11(A),

11(B) and 11(C). The first type of wave consists of a "crest" alone. The second type consists of a "trough" alone, while the third type consists of a "crest and a trough." Now we want to know what is meant by the *amplitude* of a wave.

The *amplitude* is the *height* of the wave. But more than that—this "height" is measured *from the normal position of the medium* to a *greatest displacement* of the wave. Thus, the amplitude in Fig. 11(A) is from a to b. In Fig. 11(B), the amplitude is measured from c to d. In Fig. 11(C), there are *two* places where the amplitude is measured. The distance from e to f is the amplitude, and the distance from g to h is also the amplitude, although the crest and a trough are part of a single wave. This follows from the definition of the amplitude, as being a maximum displacement *from the zero position.* (See note.*)

In your experiment with the rope on the floor, note that the wave motion will travel farther when equal amplitudes are produced regularly. Note also that the amplitude of a wave decreases in its travel through the medium. Radio waves, also, have decreasing amplitudes and this accounts for weaker signals being received at a distant station.

An important observation in studying wave motion is the amount of time that is required to complete any part of a motion. An amount of time is called a *period.* In Radio measurements, practically all observations of a *period* are made in "seconds," or "parts of a second." Thus it is customary to speak of the "period of a wave" or a "period of sickness" or the period of anything else, meaning the time required for any event to take place.

In wave motion the most common period which is observed is the duration between the beginning of one wave and the beginning of another wave. Thus, the "time per wave" would be another term for the observation of such a period. This expression clearly tells us how to find the period. Count the time, then count the waves and *divide* the time by the waves. The result will be the numerical value of the period. You will recall that *per* means *divided by.*

We use another observation in wave-motion which is called the *frequency.* The frequency can best be described as follows:

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*NOTE: Sound waves and Radio waves have amplitudes which are studied indirectly, observing the effects they produce in giving motion to parts of delicate instruments. For instance, the effects from a Radio wave can make a pointer of a sensitive meter (an oscillograph) move, and by studying the motions of the pointer **from its point of rest,** then it is possible to study the actions of the Radio wave itself. This will be described fully in a later lesson.

Frequency is "motion per time." In other words count the motions (waves) and count the time, then *divide* the waves by the time. This will show how *frequently* the waves or motions occur in a single (one) unit of time. As mentioned before, the time is usually counted in seconds.

Waves usually occur in *cycles,* so *frequency* is also spoken of as "cycles per second." No doubt you have already heard about the frequency assigned to each individual broadcasting station as being so many "cycles per second" or "kilocycles per second." It is a common practice to speak of the *frequency* of a motion as being "so many cycles" or "so many kilocycles" but you will now know that the person really meant "cycles *per second*" or "kilocycles *per second*" because *frequency* means *motions (or waves) per unit of time* and that the time is understood to be measured *in seconds.*

A period, in which a series of events or motions is repeated, is called *a cycle.* Thus, a cycle is a series of motions which repeat themselves. Let us look at Fig. 11(D) where a series of crests are sent along the rope with a regular period of waiting between each crest. Imagine yourself standing at the point *l* watching the waves going by. First, you will note a period in which a crest will pass you, then you will note a period in which no waves pass. This process will be *repeated.* The *period* between the beginning of one motion and the beginning of a similar motion is known as a *cycle.* By *counting* the *cycles* it is possible to count the waves themselves.

Now how can we represent a period or a cycle by a picture or a drawing? In other words, how could we photograph *time?* Well, we can't exactly photograph time but we can take a series of pictures of *one point* in motion and by placing the pictures end to end, and knowing the *amount of time* that it took for the point to complete the motion, we can say that the *distance between* the first picture (point) and the last picture (point) *represents* the *time.*

Thus, in Fig. 11(D) the point *l* could be photographed as it would rise and fall during the motion imparted by the wave. The individual pictures of the point, when placed end to end would give a single picture exactly like Fig. 11(D).

Therefore, if we knew the period of one cycle then we could let the *distance from i to l* represent *that period.* Of course, it would be easy to measure any other period from such information, if it is known that a given length represented a certain

amount of time, and even the frequency (cycles per second) can be measured.

Most Radio waves, and sound waves usually have one cycle of motion followed immediately by other *cycles of motion* as shown in Fig. 11 (E) where two such cycles are represented. In other words the cycles usually do not have a "period of idleness" as represented by i and n in Fig. 11 (D), unless the transmitter ceases to send out waves.

Another thing that we like to know about waves is the *actual distance* between waves. This *distance* is known as the *wavelength*. It is the actual number of feet, miles, or meters between the beginning of one wave and the beginning of a similar wave which follows it. Thus, it is the actual distance covered during one cycle of a wave.

When a stone is thrown into a body of water a disturbance is produced which extends over the surface of the water in circles centered at the place where the stone struck. The water is pushed down and aside by the stone, forming a circular ridge which expands into a larger circle, and is followed by a second circular ridge which expands, etc. The result is that the surface is soon covered by a series of circular ripples or waves which are separated by circular troughs all moving away from the center of the disturbance. The high points of the wave are called the crests; the low ones, the troughs.

An important point to understand is that although the water waves travel from where the stone was thrown into the water, the water itself does not travel except for an up-and-down or to-and-fro motion.

Having learned this much about waves, suppose the crests of water waves radiating from a central disturbance pass a certain point in a minute, say, 5 crests in one minute. Then the frequency of the waves is 5 per minute. Now suppose the distance between two consecutive crests is 10 feet. What is the velocity or speed that the wave is traveling? The answer is simple. All we have to do is to multiply 5 by 10, the result being 50 feet per minute.

I suppose you are wondering what this has to do with Radio. Just this—Broadcasting stations send out electromagnetic waves which travel at a certain speed. This speed is very great—actually 186,000 miles per second. They follow each other something like water waves only they are continuous, having a certain frequency which is determined by the operator of the broad-

casting station, and it may be some day that it will be your job among other things to see that your station maintains a constant frequency and stays at a certain wavelength to comply with the regulations of the Federal Radio Commission.

Whenever you know any two of these three things, velocity, frequency or wavelength you can always find the other by means of these relations:

$$\text{Velocity} = \text{Frequency} \times \text{Wavelength} \quad (1)$$
$$\text{Frequency} = \text{Velocity} \div \text{Wavelength} \quad (2)$$
$$\text{Wavelength} = \text{Velocity} \div \text{Frequency} \quad (3)$$

In order to assist us in memorizing these formulas we make use of a number of symbols, as we call them, and instead of spelling out the words, velocity, frequency and wavelength, we just put in place of them these symbols.

Fig. 12—Picture showing how waves are produced in a pond by throwing a stone in the water at "A." This stone starts a series of concentric ripples or waves, which spread out in all directions, affecting the piece of wood "B." The stone "A" may be compared to a Radio transmitting station and "B" to a receiving station.

For example, in Radio, we always use the letter v for velocity and for frequency we use the letter f and the Greek letter Lambda (λ) is used for wavelength.

So using our short-cut method we can rewrite the formulas given above.

$$v = f\lambda \qquad f = \frac{v}{\lambda} \qquad \lambda = \frac{v}{f}$$

(Velocity equals frequency multiplied by wavelength)

(Frequency equals velocity divided by wavelength)

(Wavelength equals velocity divided by frequency)

Fig. 12(a) shows an easy way to remember these formulas: When the finger covers one letter, it always equals the other two in the exact relationship. When one is under the other it means one divided by the other. When one is beside the other, one multiplied by the other.

The velocity of Radio waves is always the same. It is 186,000 miles per second, or 300,000,000 meters per second. (A meter is very nearly equal to 39 inches.) The velocity of light is exactly the same. The velocity of sound waves depends on what the waves are traveling through, but when traveling through air they travel about 1,100 feet a second. At any rate you see that we generally know the value of v in the above formulas, and since in Radio we always use the "Metric" system of measurements instead of the English, you must memorize the velocity of Radio waves as 300,000,000 meters per second, or as 300,000 kilometers per second. (A kilometer is equal to 1,000 meters.)

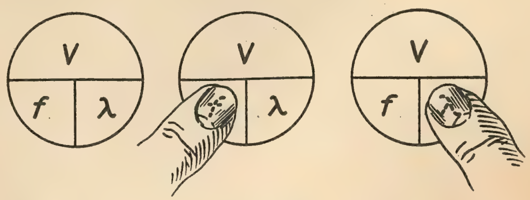

Fig. 12(a)

In most Radio work the value of the frequency generally runs very high: the frequencies used by broadcasting stations vary from 500,000 to 1,500,000 cycles per second. It is often annoying to have to use such large numbers, so we use the term "kilocycle" to mean 1,000 cycles. For example: 1,000,000 cycles per second is the same as 1,000 kilocycles; 1,500,000 cycles is the same as 1,500 kilocycles; 500,000 cycles is the same as 500 kilocycles, and so on.

So, in the formulas, which we have given, if we let v (the velocity of the waves) be expressed in kilometers, and the frequency f be expressed in kilocycles per second, we can write them as

$$\lambda = \frac{300{,}000}{f} \qquad f = \frac{300{,}000}{\lambda}$$

Remember that λ is in meters and f is in kilocycles.

Let us do a few simple problems in order to illustrate how

these formulas are used. You notice there are now only two formulas, for we already know the value of v; it is 300,000.

A broadcasting station is radiating a wave whose frequency is 750 kilocycles per second. What is the wavelength of this wave? The first formula gives us the answer; in place of f put the frequency 750 and we get

$$\lambda = \frac{300{,}000}{750} = 400 \text{ meters}$$

Once again, suppose we are receiving signals on our receiving set, which has a wavelength of 300 meters. What is the frequency of the transmitting station? This time use the second formula. Putting 300 for λ, we get

$$f = \frac{300{,}000}{300} = 1{,}000 \text{ kilocycles.}$$

PRODUCTION OF RADIO WAVES

In the case of water waves we know very well what caused them. Something dropped into the water caused the disturbance. In a similar way Radio waves may be produced. The disturbance, in the case of Radio, is produced in the ether. The only known thing that is capable of affecting the ether (name given to the medium presumed to permeate all matter and space) is the electron and the only way that electrons can produce waves in the ether is by making them move rapidly to-and-fro, so that they vibrate or oscillate. Wires are mostly used to guide the electrons along a given path. These free or moving electrons produce electromagnetic waves in the ether and the motion of the waves produced are similar in every respect to the motion of the electrons within the guiding wires. In order to radiate the Radio waves to great distances, the wire is raised to a high position and it is then called an "aerial" or "antenna."

The current from a battery flows steadily and only in one direction through the circuit. That is direct current. There are no back and forth motions in such a circuit. There is, however, another form of electric current known as "alternating current" which does not flow steadily in one direction. Alternating current continually and regularly reverses its direction of flow. There is a period of forward motion followed by a period of reversed motion.

The two periods of motion make a cycle.

A cycle of electron motion will produce a cycle of wave motion in the ether. Consequently each cycle of current flow will make a Radio wave.

In a previous paragraph it has been shown that a wire carrying current has a magnetic field about it and the strength of this magnetic field varies with every change of current. Also the magnetic field is at right angles with the current flow. When a transmitter is in operation and an alternating current applied so it will alternate between the extreme end of the aerial and the connection ground there exists an electrical strain, or electrical field as it is called, between the aerial and ground. In other words, we have a vertical electric vibration and a horizontal magnetic vibration near the aerial circuit. If the alternating current reverses its direction in the aerial circuit rapidly and uniformly there will be a uniform disturbance in the aerial circuit which will set up a Radio wave. As these Radio waves consist of both electric and magnetic vibrations they are called electromagnetic waves. The magnetic portion of the wave will be the one in which we shall be interested.

When these electromagnetic waves come in contact with the aerial circuit of a *receiving station,* they induce in it oscillations of alternating current, exactly similar to the oscillations in the transmitting aerial circuit.

TUNING A RECEIVER

You have often heard of "tuning in" a Radio receiver. You have no doubt at some time or other wondered what goes on when you change the position of the dial or dials so as to cut out one station and bring in another station. In this first lesson we will only give you a general idea of what happens.

As the proper way to learn anything is to start out with something we do know and then work to the unknown, we will start out this chapter on tuning by working with two violin strings. When two strings are in "tune" we know that they will make the same sound when plucked, or, when a bow is drawn over them.

Let us perform some experiments now with violin strings. We start out with two violins, tuned together, that is, each of the four strings of the one is exactly in tune with the corresponding string of the other. Now make any string of violin number 1 vibrate, either by plucking it or by drawing a bow

over it. If you put your ear close to violin number 2 you will hear a faint sound coming from the corresponding string in number 2 even though you have not touched it, but you won't hear a sound from the other three strings. You can do the same with any string—you will always hear a faint sound from the corresponding strings in violin number 2.

Just what has caused this curious action we will explain now. You know that sound travels in waves just as water does when disturbed. When we plucked the string we caused a disturbance which produced sound waves. Air waves are not exactly like rope waves or water waves although they follow the same laws. When a string is vibrating in one direction it compresses the air before it. As it moves in the other direction the air before it is *expanded.* There are *successive compressions* and *rarefactions,* then, which follow each other in regular order.

These waves travel in all directions just as Radio waves do, so the effect on violin number 2 will be the same if it is on a table with number 1, or under the table, or above it, or on any side of it.

When the waves produced at number 1 reach number 2 they naturally strike all the strings. One of the strings is in tune with the one producing the waves so when the crest of the first wave strikes it, the string will be pushed out of line by it, just a trifle of course. Then when the trough follows, the string will fly back and because of the strain put upon it, will fly back beyond its normal position. By the time it gets back as far as possible it is met by the crest of the second wave, and again pushed forward. This action continues and the string on violin number 2 vibrates in time with the string producing the waves.

What happens in the case of the other strings, why don't they vibrate, too? The trouble appears when the very first wave strikes it. The crest of the wave causes the other strings to move just as it did the string that was in tune but the string sprang back either before or after the crest of the second wave was there to give it its second push. So the string "cut" the waves and its motion was stopped. From this you will gather that strings vibrate at different frequencies, depending on thickness, length and tautness, or tension. If two strings vibrate (oscillate) at the same frequency they are in tune.

The word "resonance" which means the same as "tuning" will help us remember what we have talked about in the last few paragraphs. It comes from Latin words meaning to "sound

back" which is exactly what we illustrated by our experiment with the two violins. If two strings are in tune and one is caused to vibrate, the second will "sound back" and is in "resonance." So, when a Radio receiver is "tuned" to a certain station, it is also said to be "in resonance" with that station.

Coming back to Radio, let us imagine that the transmitting station is violin number 1 and the receiving set is violin number 2. If our set is in resonance "tuned" with the transmitting station, we will hear its signals—if we are not in resonance we naturally don't get the station.

We know that to tune a receiver it is necessary to turn one or more dials on the panel of the set, but just what goes on in the set when the position of the dial is changed, and what principles make it possible to tune in one station and all others out, is a matter that must be kept until a little later. However, by this time you should have a clear idea of what is meant by "tuning" and have a clear understanding of simple waves—water, sound, and also—Radio waves—as far as possible in this first lesson, which after all is just an introduction to Radio. In later lessons we shall meet the acquaintances we made in this lesson and learn to know them much better. We shall see how we can vary the amplitudes of simple Radio waves and how this will allow us to combine sound waves with the Radio waves.

FROM TRANSMITTER TO RECEIVER

Having considered the natural phenomena that make Radio possible, we are now ready to look at our receiving apparatus for a few moments. You may wonder why we don't start with the details of the transmitting apparatus, but there are several reasons why it is much better to start at the other end. In the first place, receiving apparatus is much simpler than that of transmitting. In the second place, there are many more receivers in operation than transmitters, and much more chance to see them and get on our road of repairing and servicing receivers. And last of all, after you understand the receiver it will be easy to start work on the transmitter and get a thorough understanding of it in short order.

You know that the Radio wave is sent across, "transmitted" from the transmitter, to the receiver through the ether. Remember that ether forms a part of everything in nature—that is why Radio waves travel everywhere, through houses, through the earth, through the air.

When the transmitted Radio wave cuts the receiving antenna (aerial) illustration in Fig. 13, it starts the electrons in the aerial wire moving immediately which we now know to be a very small electric current. This current is naturally at a very high frequency. It is one of the jobs of the receiver to reconvert into sound waves this high frequency current which is called Radio Frequency (R.F.) (upon which is impressed the sound waves) so that when it reaches the earphone or loudspeaker, it can become audible to the human ear. This lower frequency of sound is called "audio frequency" (A.F.). The conversion can be accomplished in one method by means of a crystal. We will learn later on just what there is about various crystals which

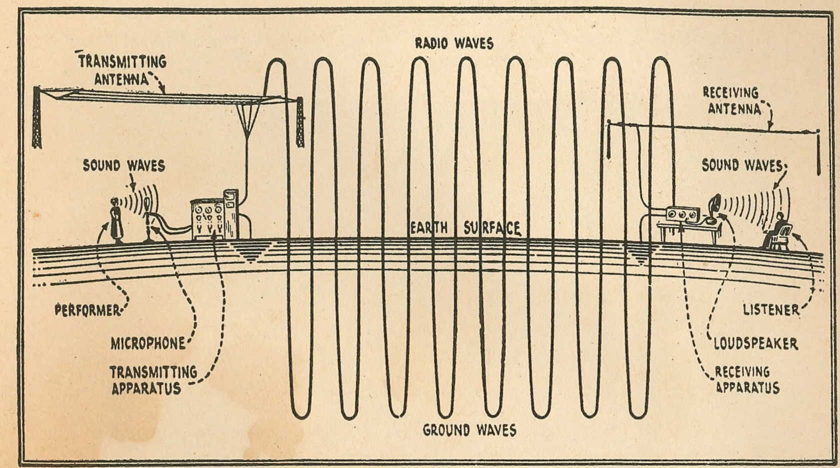

Fig. 13—Broadcasting and receiving process.

enables them to make these signals audible. In modern sets this conversion is accomplished by means of a single vacuum tube, called the detector tube, about which we shall also learn a great deal more later on.

As we said before, the signal in the form of an electric current as it comes from the aerial in most cases is very weak. If the receiver is fairly near to a powerful Radio station, the incoming signal may be strong enough to be heard by means of a simple receiver using earphones. But now-a-days we can hear signals from stations clear across the country while using a loudspeaker. How is this accomplished? Evidently the signal must be strengthened or "amplified." Both R.F. and A.F. can be amplified. This is accomplished by means of amplifying tubes. A single tube amplifies the signal only a little. Several

tubes must be used in order to amplify the signal again and again. And each amplifying tube with the other necessary apparatus represents a "state" of amplification.

Under certain conditions it is possible to make each stage of amplification increase the strength of the signal anywhere from twice to 200 times. The average amplification per stage in modern sets is about 40 times. In the development of Radio, A.F. amplification came before R.F. amplification. First a single stage was added to a detector. This was followed by a second stage. And now most modern sets have only 2 stages of A.F. amplification.

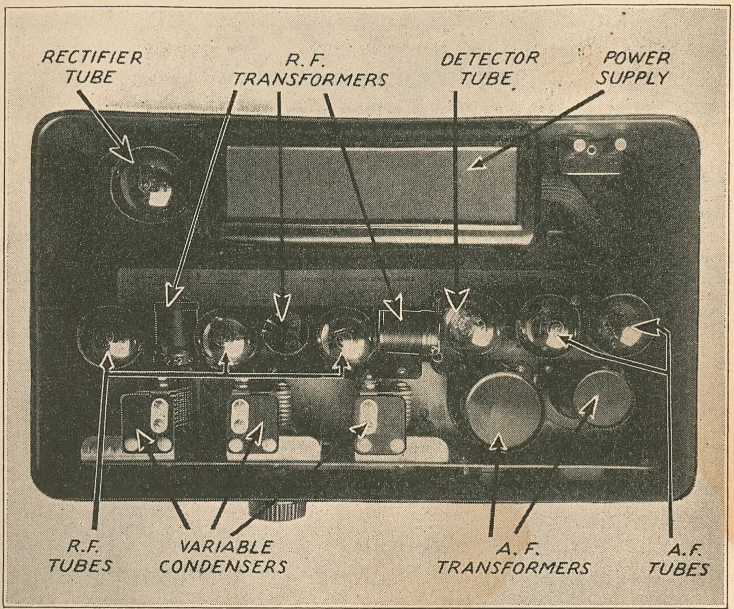

Fig. 14—Photo showing apparatus used in a typical A.C. Radio receiving set.

From this you can gather that a set consisting of tuning apparatus (coils and condenser) a detector and 2 stages of A.F. amplification will be quite satisfactory for ordinary reception. But we aren't satisfied with that. We want to reach out and get far distant stations, we want our sets to be powerful and bring in even weak signals with clearness. If a very weak Radio wave strikes our antenna, by the time it gets through the detector it is still so weak that it fails to operate the speaker, therefore no amount of audio frequency amplification will make it strong enough to be heard in the loudspeaker. We can get

around this by amplifying this very weak Radio wave before it reaches the detector by using Radio frequency amplifiers ahead of the detector, then amplifying this again by the audio frequency amplifier. R.F. amplification is also accomplished by means of vacuum tubes. Modern receivers vary, in having from 1 to 4 stages of R.F. amplification.

From what we have just said, it is clear that a receiving set can be thought of as having 4 main divisions—Tuning apparatus, R.F. amplifiers, Detector, and A.F. amplifiers.

APPARATUS USED IN A RADIO RECEIVER

We have made considerable progress in the short time we have spent in reading over this lesson. Let us go a step further —and look at the actual apparatus used in receiving sets.

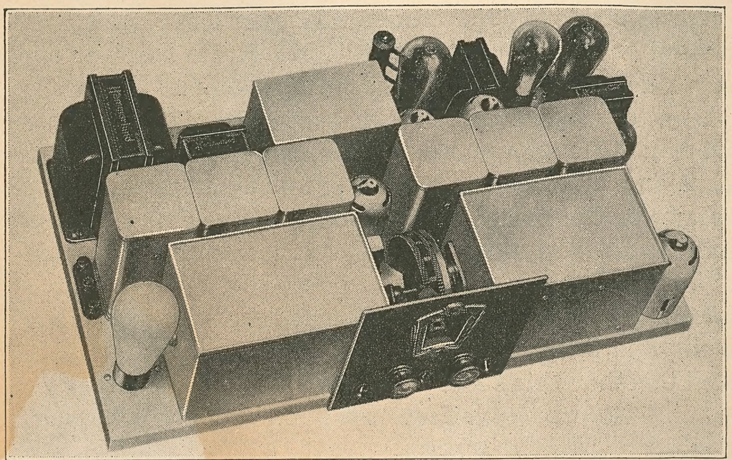

Fig. 15—Photo showing modern Radio receiver with apparatus shielded.

The one shown in the photograph (Fig. 14) employs seven vacuum tubes, that serve various purposes, depending upon what they are supposed to do. The first three vacuum tubes from the left (center) of the picture are the radio frequency tubes used to amplify the weak signals which come in from the aerial. The next tube is the detector which takes the amplified radio signals and changes them into audio signals so that they can be converted into sound by using headphones or further amplified for loudspeaker operation. The next two tubes are used to amplify the audio signals so that they can satisfactorily operate a loudspeaker.

We also see the coils of wire used for coupling one circuit

to another and for tuning the circuits to a certain frequency in conjunction with the variable condensers, the capacities of which are varied by operating a knob on the panel. At the rear of the set (top of the picture) you will notice a power supply unit and a rectifying tube. The power supply unit consists of a special transformer which changes the 110-volt alternating current supplied from the line to the required lower and higher values for the operation of the set. The lower voltages are required by the filaments of the tubes. The rectifying tube converts the current to pulsating direct current and a filter circuit smoothes out the pulsating direct current delivered by the rectifying tube and makes it pure D.C. and noiseless in action before it is applied to the plates of the vacuum tubes. A resistance unit is also used in the power supply to reduce the high rectified voltage to the values required by the plate circuits.

The Radio receiver which has just been described and illustrated is an A.C. set; that is, it is a Radio receiver operated by power taken from the house lighting system.

A battery operated receiver is very similar to this except that it uses different vacuum tubes and does not use a power unit or rectifying tube but receives its power direct from batteries.

Many of the parts, such as coils, tubes, condensers, etc., in modern Radio receivers are very well concealed by shielding. Fig. 15 will give you a fair idea of what a modern A.C. screen grid set looks like until in later lessons we dissect the set more carefully and learn all of its details.

All together this short description may seem rather unsatisfying more than likely a thousand questions are cropping up in your mind. "What is a screen grid tube?" "What is a pulsating current and a filter circuit?" Or, "What does this unit do when the set is operated?" Or, again, "Why is it necessary to have some condensers variable and some fixed?"

It is the object of this course to teach you all of these things thoroughly. The subject of Radio is a long one, but you will understand fully how all of these things work as they are described in detail in various advanced lessons of the course. For the present, familiarize yourself with the names and appearances of the various parts which enter into the make-up of a Radio receiver.

We are now nearly ready to conclude this first lesson. Before we do so, however, we wish to advise you that if there is anything in this lesson that has escaped you, or if there are things

upon which you are not very clear, read the lesson over again. Your progress in this course will depend to an enormous amount upon your ability to get out of this lesson all there is in it. If you master it thoroughly, the rest of the course will be easy and enjoyable.

TEST QUESTIONS

Number your Answer Sheet 1FR and add your *Student Number.*

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is an electric current?
2. What is the speed of the electrical disturbance traveling through a wire?
3. Describe an electromagnet and state some of its common uses.
4. What is meant by the magnetic field of a magnet?
5. State two methods that can be used to determine the direction of magnetism about a wire carrying current.
6. Station ABC broadcasting on a wavelength of 500 meters —on what frequency does it operate?
7. Why is it possible for Radio waves to penetrate thick walls?
8. What happens when Radio waves reach the receiving aerial?
9. What is the purpose of a radio frequency amplifier?
10. Explain the function of an audio frequency amplifier.